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Succession processes and development of the stand structure of a 161-year-old Norway spruce plantation under regime without silvicultural treatment

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Abstract

Background and Purpose: Regeneration and conversion of pure spruce plantations is a very important task for forest management in Europe. This subject is less marked in Croatia in view of the fact that in Croatia there are only 75,000 ha of pure coniferous plantations, which are raised on unstocked forest land. In Croatia, no investigation has yet been carried out on the development of the stand structure, succession processes of autochthonous species and methods of reforestation and conversion of spruce plantations. This study is one of the first which deals with the aforementioned problems.

Materials and Methods: Since 1956 five successive measurements (d b h and tree heights, tree-crown diameters, height of crown base, condition and position of a tree, horizontal crown projections, density and structure of regeneration, comparison of chemical and physical characteristics of soils between the plantation, natural stand and meadow) have been performed in a 161-year-old spruce plantation on a permanent experimental plot (1 ha), in which no silvicultural treatments were carried out during the last 42 years.

Results and discussion: The period of the last 42 years, during which there were no management interventions in the stand, is characterized by specific development of the stand structure. The fact is that in the old Norway spruce plantation there was a considerable potential for succession of autochthonous European beech and silver fir at the time of the first measurement in 1956. However, in spite of two thinnings performed at the beginning of the 48-year long period (66 Norway spruce trees cut per ha) and 110 naturally removed spruce trees during the last 42 years (self-thinning), the processes of beech and fir succession were very slow.

Conclusions: Results on slowed down development of the stand structure of an old spruce plantation, and on slowed down succession processes related to the absence of management interventions and delayed regeneration, are discussed in accordance with the results of spruce plantation management in Central Europe. Further investigations are necessary of the old spruce stand in two directions; under regime without silvicultural treatment (natural development) and under regime by different silvicultural methods.

INTRODUCTION

At the beginning of the 19th century considerable areas in central Europe, dominantly covered by natural broad-leaved forests, were substituted by conifer plantations. Norway spruce (*Picea abies* (L.) Karst) was the most favoured tree species (*1*). At that time higher growth rates and more valuable timber were expected from the conversion of natural broad-leaved forests into pure coniferous plantations. However, this conversion considerably changed forest vegetation from its natural condition (*2*). Because of the potential instability of pure coniferous plantations, which has been criticized for several years, conversion of spruce plantations remains an important task for forest management in Europe (*3*, *4*, *5*).

In contrast to Central Europe, almost no conversion of broad-leaved forests to coniferous plantations occurred in Croatia during the 19th century and later. During the second half of the 19th century spruce was introduced and planted in an understocked natural beech stands in the region of Gorski kotar under the influence of German families Thurn and Taxis (*6*). Furthermore, during the 19th century, spruce plantations were seeded and raised in areas in which there were no forests, but only hayfields or meadows. However, they were small and unimportant areas.

In Croatia, considerable afforestation and establishing of coniferous plantations took place in the 20th century, from 1950 to 1980. In the continental part of Croatia coniferous plantations were established on fernplots and heathland on deserted agricultural land and pastures. As pioneering species Austrian pine (*Pinus nigra* Arn.), Aleppo pine (*Pinus halepensis* Mill.) and Turkish pine (*Pinus brutia* Ten.) were planted in the region of the Mediterranean and sub-Mediterranean Karst on non-covered forest land, as well as on areas with degraded autochthonous vegetation (garrigue). Consequently, today in Croatia there are approximately 75,000 ha with coniferous plantations. Of that number, the share of spruce amounts to 55% (*7*).

The fact is that apart from rare investigations (*8*, *9*, *10*) no significant investigations on coniferous plantations have been performed, particularly of spruce. Today, investigations on the development of stand structure, succession process of autochthonous tree species, and the problems of regeneration and conversion of coniferous plantations into mixed stands composed of autochthonous tree species, have become increasingly important in Croatia. This is related to the first plantations which were established in the 1950's and which are now approximately twenty years prior to reforestation.

A 161-year-old spruce stand, in which several consecutive measurements have been performed since 1956 on a permanent experimental plot, was chosen as the object of this investigation. The aim was to present some general results on stand structure development of an old Norway spruce plantation and processes of succession in conditions of delayed stand reforestation and absence of management interventions during the course of a long management period, and to discuss the practice and experience of Central and West Europe in regeneration and conversion of spruce plantations.

Study site

The study was conducted in the area of Croatian selection forests in the region of Gorski kotar. This is a pre-Alpine phytogeographic region of Croatia (45° 20' N, 14° 48' E) on the steep slope (20-30%) of the Risnjak mountain at an elevation of 700-770 m. Soils are moderately deep eutric cambisols and shallow rendzic leptosols, derived from compact limestone parent material of the Triassic period. Diversity of the relief with numerous Karst phenomena gives the soil small-scale heterogeneity. Average annual temperature of the study site is 7.7° C and the average annual precipitation for the area is 2,486 mm (Delnice weather station, 700 m elevation).

The natural forest surrounding the site was classified as European beech-silver fir forest on dolomite, *Omphalodo-Fagetum* Marinček *et al*. 1992 (*11*). Such forests grow on limestone and dolomites, luvic soils, calcimelanosols and calcicambisols with abundant flora. The forest community is situated between two belts of relatively pure beech forests at elevation of 600-1,100 m, more or less on all terrains, slopes and expositions. It is extremely rich in species of Illyrian and south-European flora, and species which are found in cooler climates with more precipitation (*Omphalodes verna, Haquetia epipastis, Euphorbia carniolica, Scopolia carniolica, Mercurialis perensis, Rhamus falax, Aremonia agrimonoides, Lamium orvala*, etc.). It is assumed that this forest community, prior to clearing and transformation into meadow was located on the area of the present old spruce plantation. The old Norway spruce plantation was established in 1843. The area of the plantation is 29.30 ha. According to forest management plans and manuscripts, the initial density of planting was about 5,000 plants per ha. Silvicultural treatments were not performed until 1956. At the beginning of investigation period, autochthonous tree vegetation was included within the plantation.

MATERIAL AND METHOD

A square plot, 100 x 100 m, was established and laid out in 1956, at the time when spruce plantation was 113 years old. A buffer zone 30 m in width was arranged around the plot. Diameter at breast height was measured on all trees over 2.5 cm on the plot. A strip, 10 m in width and 100 m in length, was formed in the middle of the plot. All trees in the strip were numbered. The trees were described in detail and measured (2 crosswise diameters, height, crown diameter, height of crown base, vitality, condition and position of the tree). In the course of 1957 measurement and thinning were repeated, and 39 spruce trees were felled. The following measurement was performed in 1962, when 27 spruce trees were felled. Since then no trees have been felled on the plot.

On the basis of old data (archives), the plot was renewed and measured in 1994, using the same method as

TABLE 1

Density, basal area, standing volume and mean d b h according to tree species and inventory years.

		Year of inventory				
		1956	1957	1962	1994	2004
Norvay spruce	N (ha^{-1})	339	300	273	201	163
	BA (m^2 ha^{-1})	48.67	44.49	41.02	41.44	36.98
	V (m^3 ha^{-1})	705.7	644.6	609.5	646.6	585.1
	DBH_m (cm)	42.8	43.5	43.7	50.6	53.8
Beech	N (ha^{-1})	478	455	690	577	481
	BA (m^2 ha^{-1})	4.44	3.86	4.48	7.53	8.25
	V (m^3 ha^{-1})	29.8	25.1	20.6	59.7	72.8
	DBH_m (cm)	10.9	10.4	9.1	12.9	14.8
Silver fir	N (ha^{-1})	35	34	140	69	66
	BA (m^2 ha^{-1})	0.08	0.07	0.31	0.28	0.29
	V (m^3 ha^{-1})	0.08	0.03	0.2	1.08	1.35
	DBH_m (cm)	5.3	5.2	5.3	7.2	7.3

N-number of trees; BA-basal area; V-volume; DBH_m-mean diameter

in 1956. Additionally, the amount and structure of the young growth was determined on the strip 2 x 100 m, in the middle of the plot. The same measurement on the plot was repeated in 2004. In addition, all numbered trees on the strip, 10 x 100 m, were measured and horizontal crown projections recorded. On three sites, i.e. in the spruce plantation plot, the neighboring natural beech and fir stand and the neighboring meadow, pedological profiles were dig out up to the depth of parental substrate for the purpose of defining soil types and taking of samples for laboratory analysis.

Calculation of volume was performed by means of volume tables according to Pranjic (*12*). Spruce was determined as the first site class and beech the second site class. Based on tree measurements in the strip 10 x 100 m, vertical profile and spatial distribution of trees (*AutoCad2000, CorelDraw*) were obtained, showing proportional relation between tree height, stem length and width and length of the crown (*13*). Physical and chemical analyses of soil were performed in the laboratory.

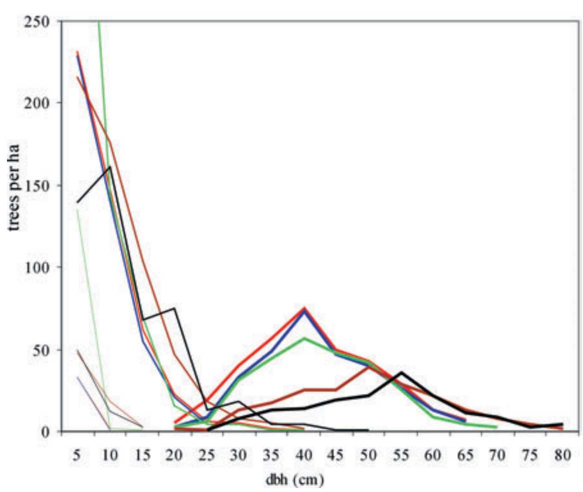

Figure 1. *Diameter distribution according to tree species and the five successive measurements (1956 – red line, 1957 – blue line, 1962 – green line, 1994 – brown line, 2004 – black line). Bold line – Norway spruce, medium line – European beech, thin line – silver fir.*

RESULTS

Based on five previous measurements (1956, 1957, 1962, 1994 and 2004) the development of the spruce stand structure was determined and is presented in Figure 1. The Figure shows that the stand consists of three parts. Planted spruce trees dominate with regard to diameters and heights. Mean height of a spruce tree in 1956 was 33.2 m, and in 2004 37.5 m. Spruce trees showed bell-shaped distribution. Since 1956 gradual shifting of the distribution has occurred towards the right, and it has become more extended and flatter. The other part of the stand, an underwood layer, forms in a natural way through the accession of beech with occasional sycamore. Beech tree distribution shows marked decline. During the first three measurements, differences in distribution were negligible, apart from a great number of beech trees in the first diameter class in 1962 which amounted to 450. Compared to the first three measurements, measurements in 1994 and 2004 confirmed a slight shifting of beech trees to the right. Naturally accessed fir forms a suppressed part of the stand in view of its small dimensions and frequency. Figure 1 shows a slight shift in the distribution of fir trees from the first three measurements to the last two measurements. An exception was the large number of fir trees measured in 1962 in the first diameter class, which amounted to 135 plants.

Figure 2. *Sample of cross-section taken at stem base (0.00 m) of the silver fir.*

Changes in the total number of trees, basal area, growing stock and mean diameter of the spruce, beech and fir are shown in Table 1. A trend of constant decrease in the number of spruce trees can be seen. As after 1962 no felling was carried out for 42 years, 110 spruce trees were removed from the plot by natural selection. As the volume of these 110 trees and 66 trees felled was previously considerably higher than the accumulated volume increment, the growing stock of the spruce has decreased by 120 m^3 over the last 48 years. The basal area has decreased by 11.7 m^2, while the mean diameter has increased by 11 cm. The large number of beech trees, which had oscillated in the course of time due to recruitment and die back, remained the same as in the first measurement. However, due to a shift in distribution of beech trees to the right, an increase occurred in the basal area, growing stock and mean diameter of the beech trees. The number of fir trees doubled in relation to the initial number and mean diameter remained the same.

According to external appearance, the majority of young fir trees are suppressed. This can be confirmed by the following fact. The age of a felled fir tree of 5.2 cm in diameter, 2.91 m in height and 2.25 m stem length was found to be as high as 93 years (Figure 2).

Vertical profile and spatial distribution of trees (Figure 3) show the condition on part of the plot measured in

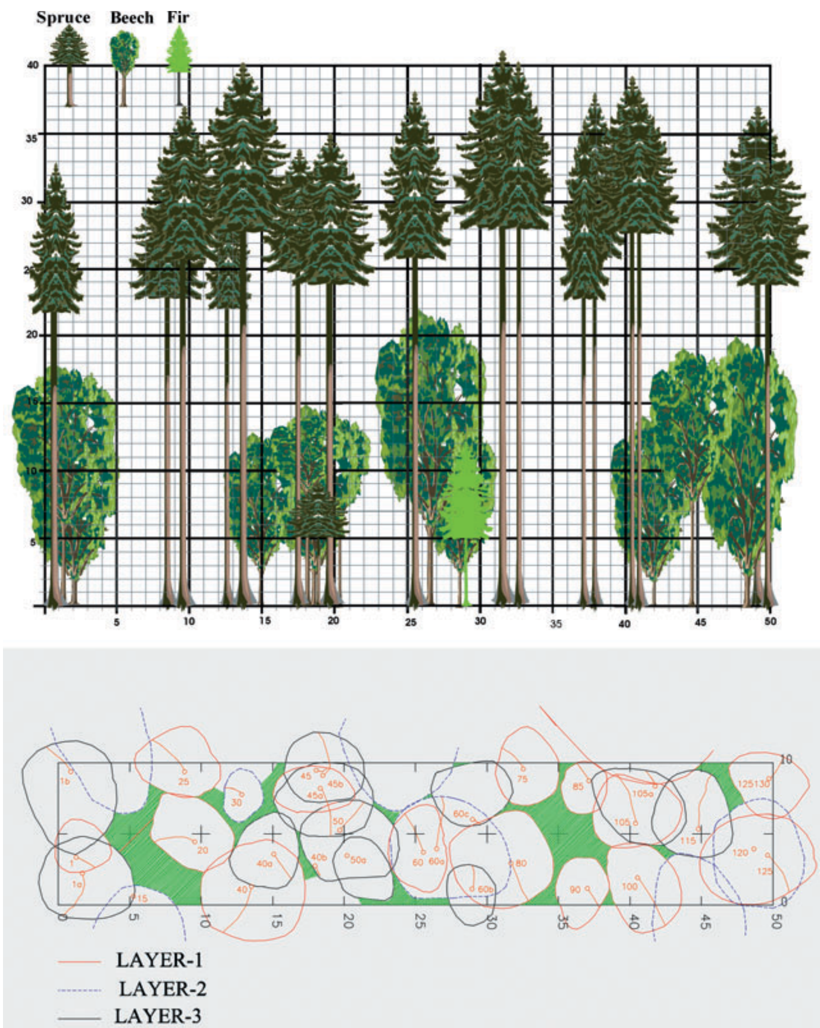

Figure 3. *The sample of spatial distribution of trees, crown projections and vertical profile of the stand on the 10 x 50 m strip.*

TABLE 2

The comparison of density and height structure of silver fir and beech regeneration between two last inventories.

Height classes (cm)	Density of regeneration (number of plants per ha)									
	silver fir		beech		sycamore		elm		mountain ash	
	1994	2004	1994	2004	1994	2004	1994	2004	1994	2004
< 30	4,650	8,950	100	250	5,800	10,950	250	250	500	600
31–60	50			200	850	2,350	150	250		50
61–130			350	100	150	350			100	
131–150			100	50						
151–200				50						
201–250			50	100						
251>			650	200						
Total	4,700	8,950	1,250	950	6,800	13,650	400	500	600	650

TABLE 3

Chemical properties of soil samples. Site 1 – Norway spruce plantation; Site 2 – neighbouring nature fir and beech stand; Site 3 – neighbouring meadow.

Analyses	Unit	Site 1				Site 2		Site 3	
		depth (cm)							
		1–6	8–20	28–45	50–70	1–5	10–35	1–4	10–40
pH/H_2O		7.7	7.6	8.1	8.2	7.2	7.8	7.3	7.4
pH/M-KCl		7.0	6.9	7.5	7.8	7.0	7.4	6.8	6.9
Total nutrients									
humus	(%)	12.93	8.70	3.77	1.95	30.77	9.80	17.25	4.73
C	(%)	7.52	5.06	2.19	1.13	17.89	5.70	10.03	2.75
N	(%)	0.66	0.53	0.20	0.08	1.39	0.56	0.82	0.26
C/N		11.39	9.55	10.95	14.13	12.87	10.18	12.23	10.58
K_2O	(mg/100 g)	15.9	10.6	4.4	2.7	16.7	6.9	25.3	6.2
P_2O_5	(mg/100 g)	1.0	0.5	0.3	0.7	7.3	2.3	2.2	0.5
$CaCO_3$	(%)	1.68	2.51	14.23	39.35	3.62	15.41	5.46	4.20

2004. The profile shows a dominant upper storey of spruce trees, 37.5 m average height, average crown width 5.44 m, and a lower layer with naturally accessed beech trees with average height of 14.6 m and average crown width of 6.20 m. Single and suppressed fir trees were found under the beech trees. Crown-covered soil of 87.53% was determined on the basis of spatial distribution of trees and crown projections.

Density of natural regeneration according to species and height classes, obtained in 1994 and 2004 inventory years, is shown in Table 2. It can be seen that natural regeneration of autochthonous tree species (silver fir, beech, sycamore and other noble broad-leaved trees) was registered, whilst Norway spruce regeneration was not registered.

Calcicambisol on dolomite (deep to moderately deep eutric cambisol) prevails in the investigated region. By chemical analyses of the soil it was determined that the soil in the neighboring natural stand of fir and beech had a higher content of nutrients (C, N, K_2O and P_2O) and is richer in humus than the soil in the Norway spruce plantation. The same was valid for the soil which lay under meadow vegetation. On the other hand, it is of interest to see that pH/H_2O and pH/M-KCl were about the same on all sites (Table 3).

It was determined that, according to physical properties calcicambisol on dolomite in the Norway spruce plantation belongs to light clays to clayey loam, while soils in the natural stand of spruce and fir in the meadow are loamy clay.

DISCUSSION

It is difficult to assume how the old spruce plantation developed until 1956. However, the stand structure of the Norway spruce plantation at the age of 113 years (1956) indicates great similarity to Wiedemann's growth yield table, for the best site quality class. Furthermore, the period of the last 42 years, during which there were no management interventions, is characterized by specific development of stand structure (Table 1, Figure 1). This can serve as a good example for investigation and determination of retarted processes of succession of natural tree species and conversion in conditions of delayed regeneration of spruce plantations.

The prescribed lower limit of rotation for spruce in Croatia amounts to 80 years (RFM 1997). On the other hand, according to a theoretic model (Wiedemann), development of an even-aged spruce stand ends in the 120th year. In usual circumstances, reforestation of a spruce plantation should have occurred between the age of 80 and 120 years. Reforestation of pure Norway spruce plantations in central and western Europe represents conversion into mixed coniferous and broad-leaved stands (*3*, *5*, *14*, *15*, *16*), and transformation to uneven-aged mosaics of mixed continuous cover forest (*1*). According to Kenk and Guehne (*1*) the stands being transformed are defined by ages from 100 and more years and target diameter between 45 and 60 cm d b h. As transformation to uneven-aged and mixed stands usually starts 20 to 60 years before the end of rotation, a question arises of how late the transformation in the investigated old spruce plantation was and how long the rotation will be.

The occurrence of succession processes in artificial Norway spruce plantations (*17*) provided potential for conversion into mixed and more stable stands composed of more naturally occurring species (e.g. beech, fir). On the other hand, it is necessary to consider direct seeding of European beech below the canopy of Norway spruce trees (*5*, *14*), underplanting below the canopy, or clear felling at the end of rotation and replanting (*1*). The fact is that there was in the old Norway spruce plantation a considerable potential for succession of autochthonous European beech and silver fir at the time of the first measurement in 1956. This is definitely closely connected with the vicinity of seed-bearing beech and silver fir trees from neighboring fir-beech stands. However, in spite of two thinnings performed at the beginning of the 48-year long period (66 Norway spruce trees cut per ha) and 110 naturally removed spruce trees during the last 42 years (self-thinning), the processes of beech and fir succession were very slow (Figure 1, Table 1). This particularly refers to young fir trees, which have mostly suppressed growth (Figure 2). Although it is well known that fir trees can have delayed growth for many years, and later continue to grow normally in more favourable conditions, it is questionable whether such young fir trees will in the future reach the expected quality and target diameter.

A two-storey type and great crown cover (Figure 3) realized in 2004 explain the slow processes of succession and development of autochthonous tree species and conversion of the old Norway spruce plantation. If the conversion had started 50 years ago with successive canopy openings, it would have led to more vertically structured and more diverse stand type.

Natural regeneration of autochthonous broad-leaved and silver fir trees (Table 2) indicates the existence of succession potential. However, only the beech, which covers all height classes of young plants, can be regarded as having continuity of succession, albeit with an extremely small number of plants. Furthermore, a significant progressive trend of sycamore seedlings and saplings is noticeable. On the basis of the data in Table 3 it can be concluded that the number of young fir plants (seedlings) oscillates. Following their occurrence in large numbers, many fir plants die back while remaining trees do not succeed in reaching a height class above 60 cm. In spite of the large number of mature and seed-bearing trees of Norway spruce, not one young spruce tree was found. This can be explained by the absence of canopy openings. Generally, the density of natural regeneration is several times smaller in relation to the results obtained by Diaci (*18*) in an old Norway spruce plantation in Slovenia. This is understandable and normal in view of the fact that he investigated the success of natural regeneration in an experiment with different sized gaps (0.02-0.26 ha). In the same way the results according to Kenk (*19*) indicate that increased opening-up of canopies improves regeneration success. In this context Hohenadl (*20*) and Mosandl (*21*) found successful development of beech, silver fir and sycamore under diffuse canopy openings and therefore suggested shelterwood system as an appropriate silvicultural measure in mountain mixed forests of silver fir and beech. Hannerz and Hanell (*22*) suggested shelterwood cutting also for forests on fertile peatland sites.

It is a fact that biochemical and chemical changes in soil occur concurrently with the processes of conversion and regeneration of old spruce plantations (*15*). In this investigation, differences in some chemical and physical characteristics of soils were only preliminarily determined between pure spruce plantation, natural fir-beech stand and meadow (Table 3). The obtained results, indicating that the soils from the natural fir-beech stand and meadow are richer in nutrients and humus than the soils from spruce plantations, were expected. However, a less expected result revealed approximately the same pH value for all sites (6.8-7.8 in 0.01 M KCl). This is significantly higher compared to the findings of Zhong and Makeschin (*15*) of very low pH value (2.9 – 3.5 in 0.01 M $CaCl_2$). Spontaneous regeneration could be limited by the thickness of Norway spruce litter. According to findings of Prach *et al*. (*23*), dense herb cover and thick layer of slowly decaying litter on secondary meadows are considered the main factors inhibiting the establishment of woody species. On the other hand, Herault *et al*. (*24*) found that, on alluvial soils under low density Norway spruce stands, the thickness of spruce litter does not appear to be a limiting factor, at least for large-seeded tree seedlings. Therefore, further systematic investigations should be carried out of physical, biochemical and chemical changes in soil during the processes of conversion and regeneration of the investigated old spruce plantation.

CONCLUSION

This paper presents some general results of the stand structure development in an old Norway spruce plantation and slow processes of succession in conditions of delayed stand regeneration and absence of any management interventions during a long period. On the other hand, the studied and discussed practice and experience of central and western Europe in interventions for regeneration and conversion of spruce plantations (*1*, *19)* suggest the practice of standard, normal management of pure spruce plantations.

Although in Croatia there are not as many pure spruce plantations as in central and western Europe, during their management care should be taken in plantations where conditions are favorable, to promptly commence with regeneration and conversion into more stable, mixed and natural stands. A smaller part of old cultures can be left to »natural development« because the knowledge which can be obtained from natural processes is valuable. On the basis of this knowledge it is possible to determine the advantages of normal management. In this respect, future investigation on the permanent experimental plot should be established in two parallel directions. Actually, further natural processes should be monitored on the plot as a reference plot with no management interventions, and the success of regeneration, conversion and transformation by application of different silvicultural methods should be monitored on newly established plots.

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